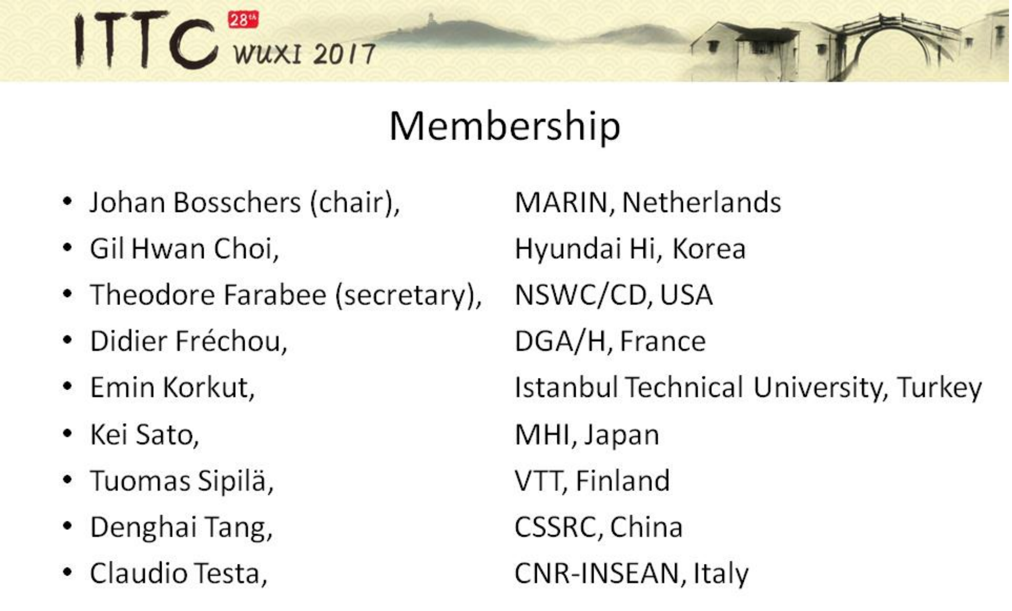
Specialist Committee on Hydrodynamic Noise

Presentation & Discussion at the 28th ITTC Conference

ITTC 28th WUXI 2017

Specialist Committee
On
Hydrodynamic Noise



ITTC 28th WUXI 2017

Membership

Johan Bosschers (chair),	MARIN, Netherlands
Gil Hwan Choi,	Hyundai Hi, Korea
Theodore Farabee (secretary),	NSWC/CD, USA
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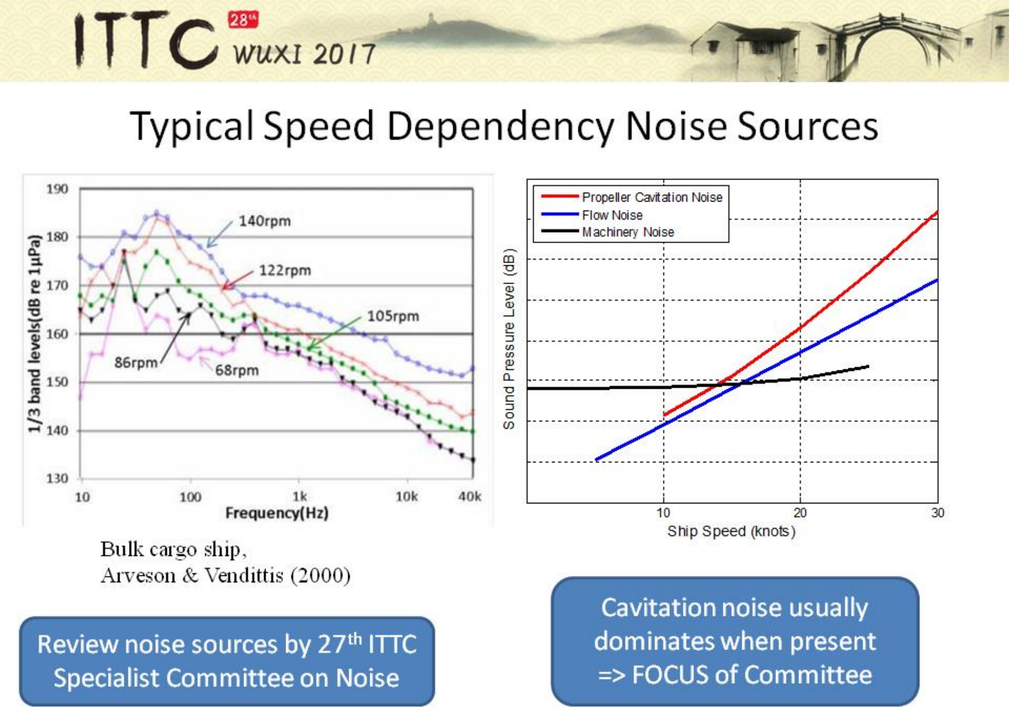
Kei Sato,	MHI, Japan
Tuomas Sipilä,	VTT, Finland
Denghai Tang,	CSSRC, China
Claudio Testa,	CNR-INSEAN, Italy

Meetings

- Istanbul, Turkey, Istanbul Technical University, March 2015
- Espoo, Finland, VTT, February 2016
- Washington, USA, NSWC/CD, October 2016
- Val-de-Reuil, France, DGA/H, April 2017

Outline - Terms of References, re-organized

- (6) Review Noise Regulation and Standards
- (2) Review Scale Effects
- (7) Review Numerical Prediction Methods
- Full Scale Noise measurements
    - (1A) Guidelines
    - (4A) Uncertainties & Variability
    - (5) Shallow water
- Model Scale Noise measurements
    - (1B) Guidelines
    - (4B) Uncertainties & Variability
    - (3) Prediction of full scale values
- (8) Benchmarking tests
- Conclusions & recommendations



Typical Speed Dependency Noise Sources

Bulk cargo ship,
Arveson & Vendittis (2000)

Review noise sources by 27th ITTC Specialist Committee on Noise

Cavitation noise usually dominates when present => FOCUS of Committee

Relevance Ship Underwater Radiated Noise (URN)

- Ship signature (military ships)
- Self-noise for sonar operation
- Influence on fish behavior (fishery research and fishing vessels)
  - ICES CR209 norm (1995)
- Influence on fish and marine mammals, in general
  - awareness in 1980's
  - IMO
    - 2008: noise from commercial shipping in relation to marine environment on agenda
    - 2014: non-mandatory guidelines (MSFC/66/17)
  - EU Marine Strategy Framework Directive (2010), URN included as descriptor for Good Environmental Status

See review 27th ITTC Specialist Committee on Noise

Outline

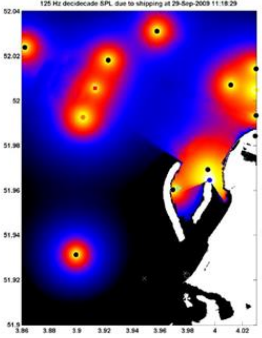
- (6) Review Noise Regulation and Standards
- (2) Review Scale Effects

Term of Reference #6:
Update the overview of national and international regulations and standards regarding hydrodynamic noise.

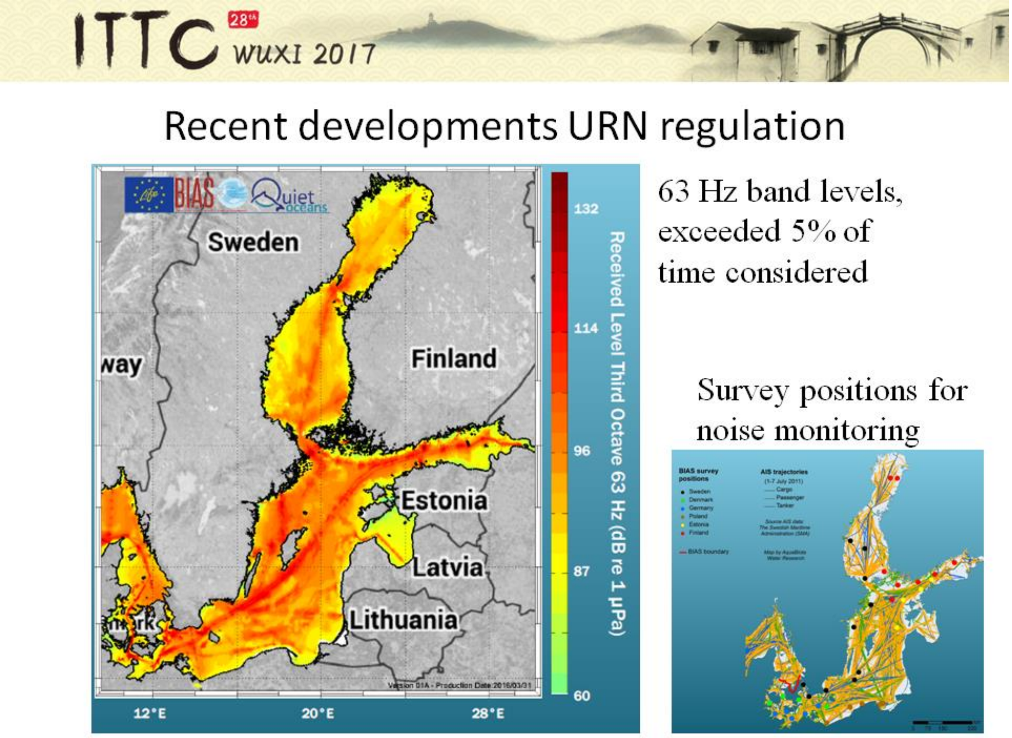
  - (3) Prediction of full scale values
- (8) Benchmarking tests

Recent developments URN regulation

- EU Noise monitoring task group
  - includes ACCOBAMS, ASCOBAMS, OSPAR)
- EU projects AQUO, BIAS and SONIC
- Procedure noise mapping
  - – AIS data
  - – Ship source model (e.g. Ross / Wales-Heitmeyer)
  - – Noise propagation model
  - – Bathymetry of region
  - – Hearing threshold fish / mammal + depth
  - – Convert data to 2-D maps
    - Integrate over time and depth (and possibly frequency)


Snapshot 125 Hz

SONIC (TNO)



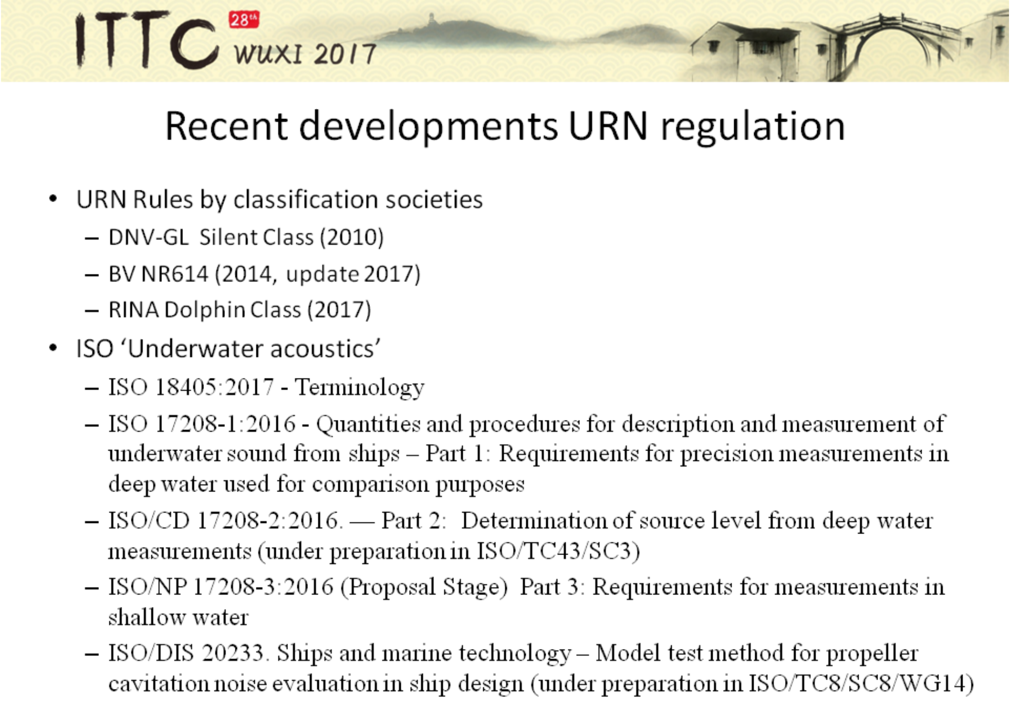
Recent developments URN regulation

63 Hz band levels, exceeded 5% of time considered

Survey positions for noise monitoring

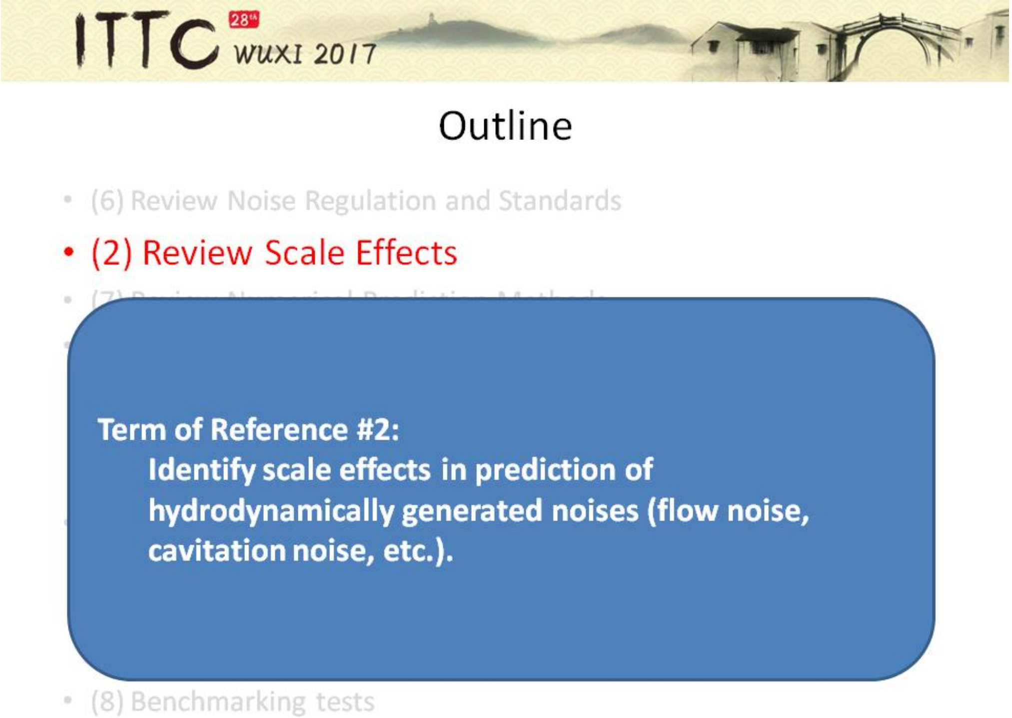
Recent developments URN regulation

- US:
  - NOAA (2016) Ocean Noise Strategy Roadmap
  - FWS & NMFS (2016) policy revision on conserving imperiled wildlife
- Asia: No activities
- IMO:
  - [No activities known at time of writing Committee Report]
  - MEPC (2017) 71-1605, submitted by Canada
    - Ask for international cooperation and exchange of information on this subject
- Other (2017)
  - Harbour reduction fees in Canada if ship complies with URN standard
  - URN included in 'Green Marine' environmental program



Recent developments URN regulation

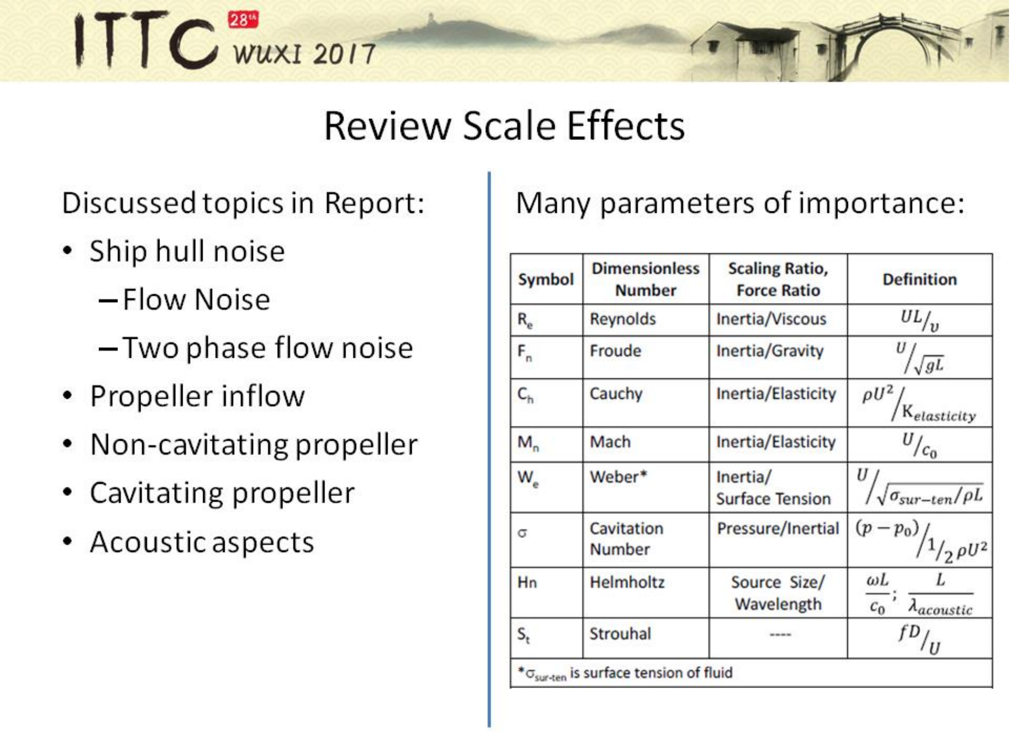
- URN Rules by classification societies
  - DNV-GL Silent Class (2010)
  - BV NR614 (2014, update 2017)
  - RINA Dolphin Class (2017)
- ISO 'Underwater acoustics'
  - ISO 18405:2017 - Terminology
  - ISO 17208-1:2016 - Quantities and procedures for description and measurement of underwater sound from ships – Part 1: Requirements for precision measurements in deep water used for comparison purposes
  - ISO/CD 17208-2:2016. — Part 2: Determination of source level from deep water measurements (under preparation in ISO/TC43/SC3)
  - ISO/NP 17208-3:2016 (Proposal Stage) Part 3: Requirements for measurements in shallow water
  - ISO/DIS 20233. Ships and marine technology – Model test method for propeller cavitation noise evaluation in ship design (under preparation in ISO/TC8/SC8/WG14)



Outline

- (6) Review Noise Regulation and Standards
- (2) Review Scale Effects
- (7) Review Numerical Prediction Methods
- (8) Benchmarking tests

Term of Reference #2:
Identify scale effects in prediction of hydrodynamically generated noises (flow noise, cavitation noise, etc.).



Review Scale Effects

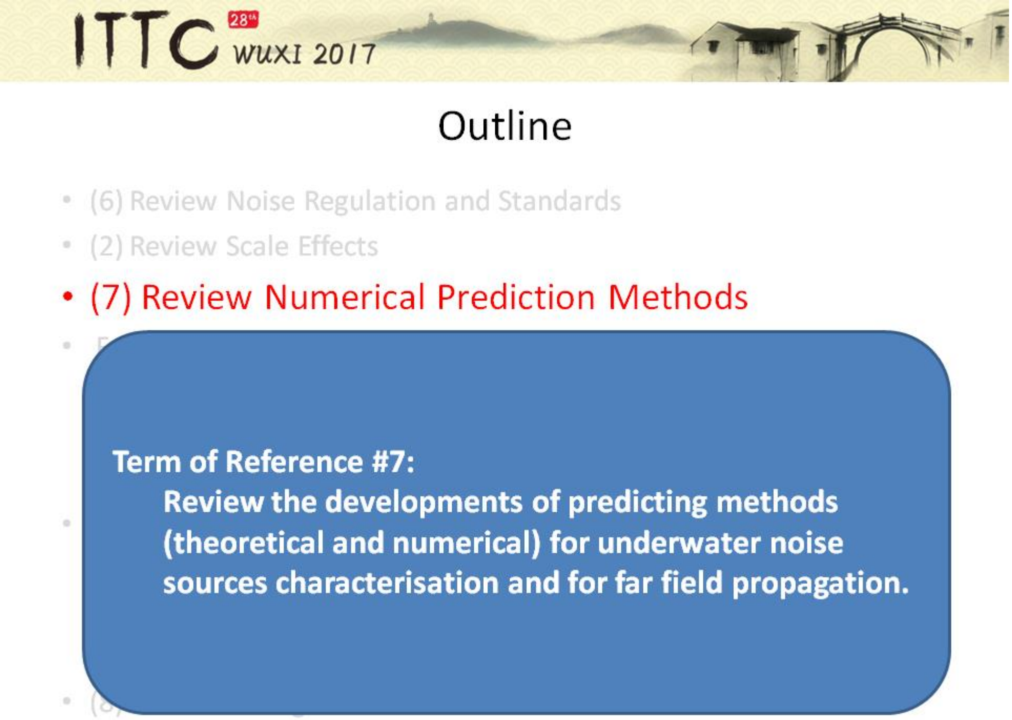
Discussed topics in Report:

- Ship hull noise
  - Flow Noise
  - Two phase flow noise
- Propeller inflow
- Non-cavitating propeller
- Cavitating propeller
- Acoustic aspects

Many parameters of importance:

Symbol	Dimensionless Number	Scaling Ratio, Force Ratio	Definition
R_e	Reynolds	Inertia/Viscous	UL/υ
F_n	Froude	Inertia/Gravity	$U/\sqrt{gL}$
C_h	Cauchy	Inertia/Elasticity	$\rho U^2/K_{elasticity}$
M_n	Mach	Inertia/Elasticity	U/c_0
W_e	Weber*	Inertia/ Surface Tension	$U/\sqrt{\sigma_{sur-ten}/\rho L}$
σ	Cavitation Number	Pressure/Inertial	$(p-p_0)/\tfrac{1}{2}\rho U^2$
Hn	Helmholtz	Source Size/ Wavelength	$\frac{\omega L}{c_0};\ \frac{L}{\lambda_{acoustic}}$
S_t	Strouhal	----	fD/U

*$\sigma_{sur\text{-}ten}$ is surface tension of fluid

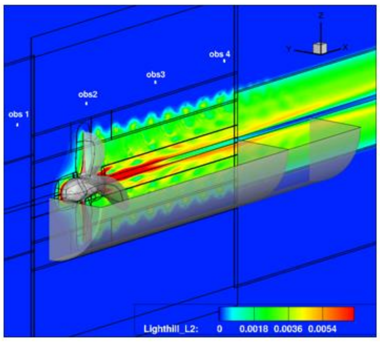


Outline

- (6) Review Noise Regulation and Standards
- (2) Review Scale Effects
- (7) Review Numerical Prediction Methods

Term of Reference #7:
Review the developments of predicting methods (theoretical and numerical) for underwater noise sources characterisation and for far field propagation.

Review Numerical Prediction Methods



Testa et al (2017)

Acoustic analogy:

Two step approach:

1. Hydrodynamic sources of sound
   - Non-cavitating propeller
   - Cavitating propeller
2. Noise prediction

e.g. Ffowcs Williams & Hawkings equations (FW-H)

- Linear terms ('thickness' + 'loading')
- Non-linear terms (vorticity, volume integral)

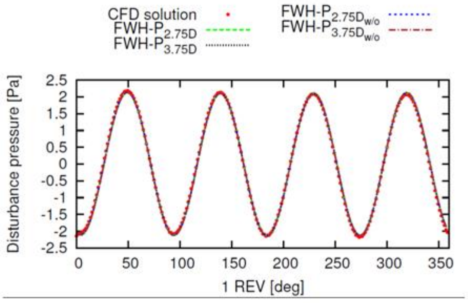
Integration surface can be on body or in free field ('permeable approach')

Unbounded space and constant speed of sound

Review Numerical Prediction Methods

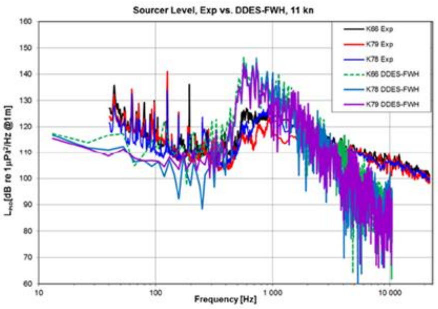
Verification Study FW-H

Test et al (2017)

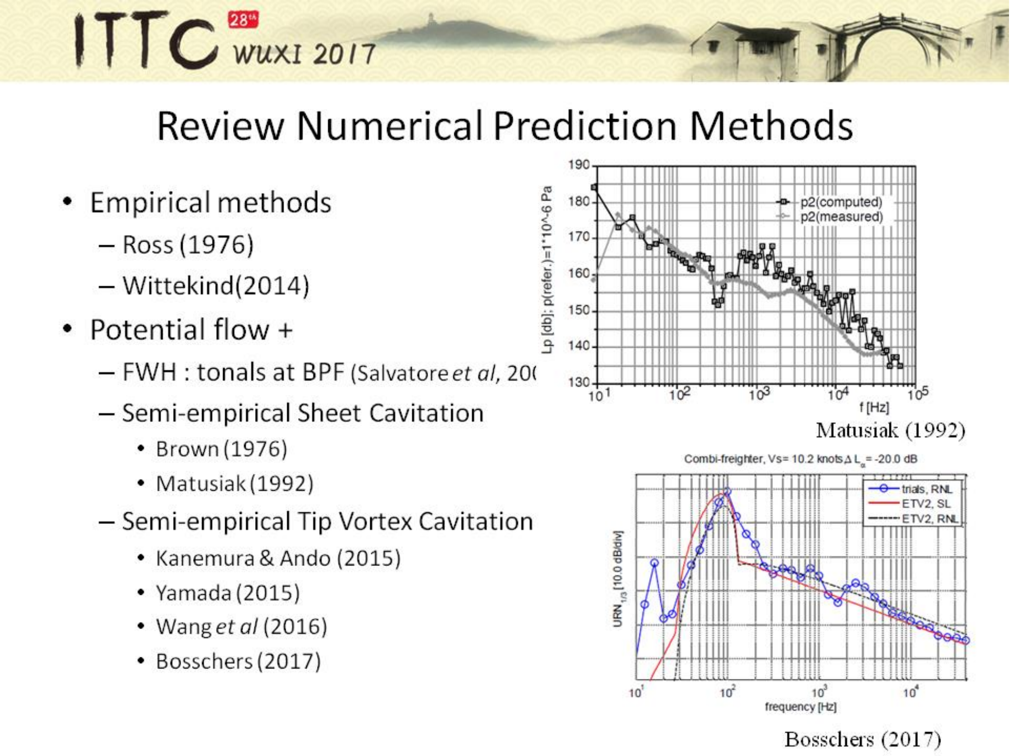


URN prediction Coastal tanker, model scale

Li *et al.* (2015)



- First results presented in literature for cavitating ship propellers
- Still some issues to be resolved (e.g. end cap problem, numerical noise)
- Noise predictions require much more effort from CFD (grid size, time step, turbulence model, two-phase flow model and compressibility effects, ...)

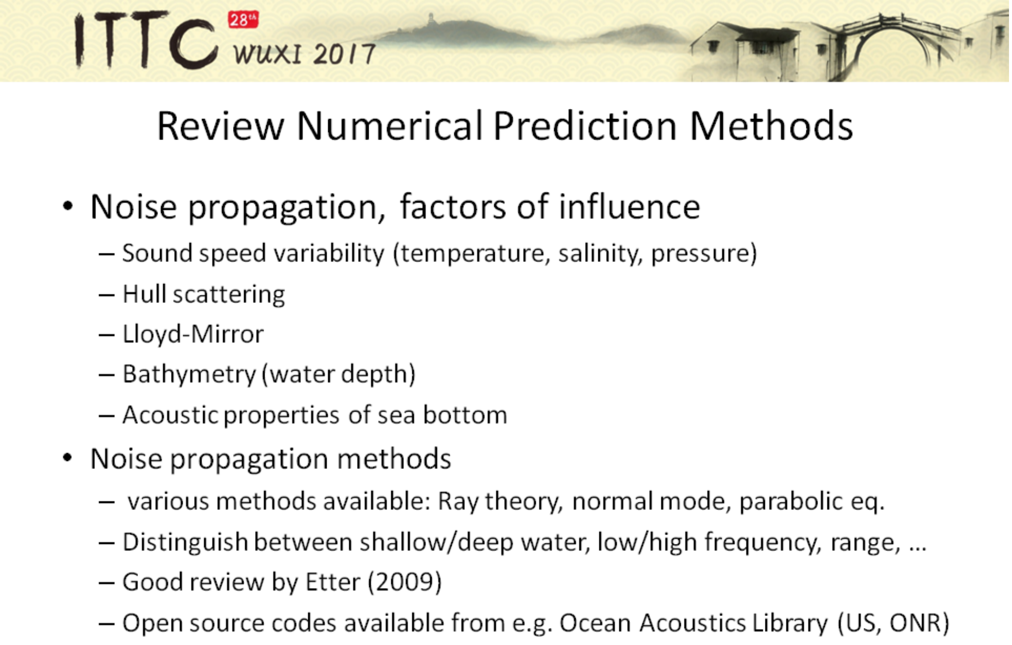


Review Numerical Prediction Methods

- Empirical methods
  - Ross (1976)
  - Wittekind(2014)
- Potential flow +
  - FWH : tonals at BPF (Salvatore *et al*, 20
  - Semi-empirical Sheet Cavitation
    - Brown (1976)
    - Matusiak (1992)
  - Semi-empirical Tip Vortex Cavitation
    - Kanemura & Ando (2015)
    - Yamada (2015)
    - Wang *et al* (2016)
    - Bosschers (2017)

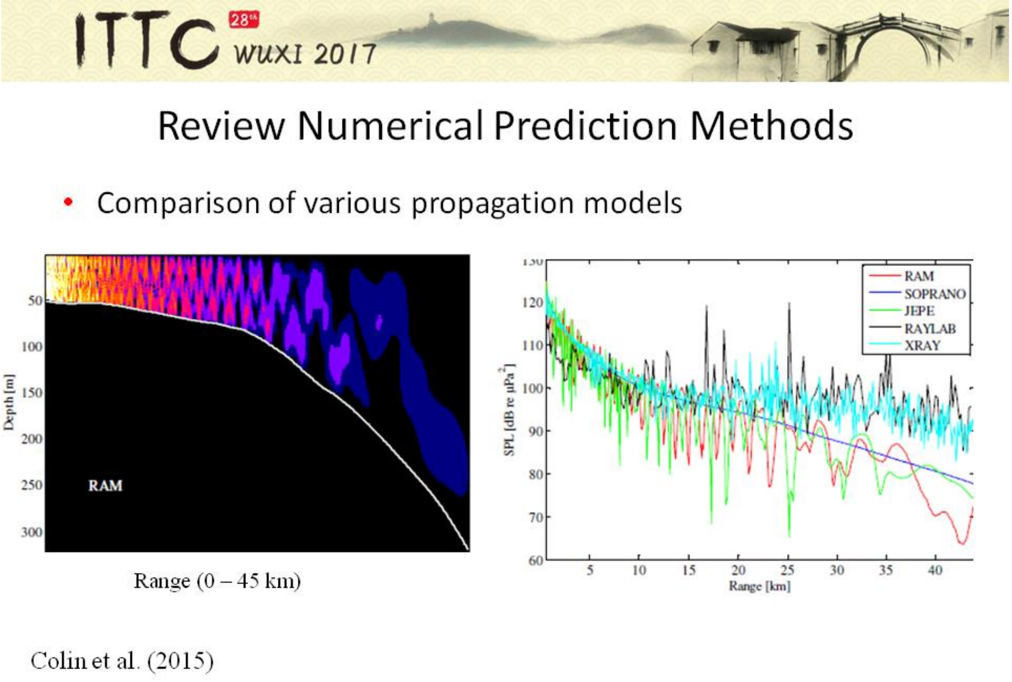
Matusiak (1992)

Bosschers (2017)



Review Numerical Prediction Methods

- Noise propagation, factors of influence
  - Sound speed variability (temperature, salinity, pressure)
  - Hull scattering
  - Lloyd-Mirror
  - Bathymetry (water depth)
  - Acoustic properties of sea bottom
- Noise propagation methods
  - various methods available: Ray theory, normal mode, parabolic eq.
  - Distinguish between shallow/deep water, low/high frequency, range, ...
  - Good review by Etter (2009)
  - Open source codes available from e.g. Ocean Acoustics Library (US, ONR)



Review Numerical Prediction Methods

- Comparison of various propagation models

Range (0 – 45 km)

Colin et al. (2015)

Outline

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FULL SCALE NOISE MEASUREMENTS:

Term of Reference #1:

Continue development of the guidelines produced during the 27th ITTC and monitor how these guidelines are being implemented by the towing tank community.

Term of Reference #4:

Review uncertainties associated with full scale noise measurements, including variability between sister ships and influence of operational conditions during sea trials, such as manoeuvring and sea state.

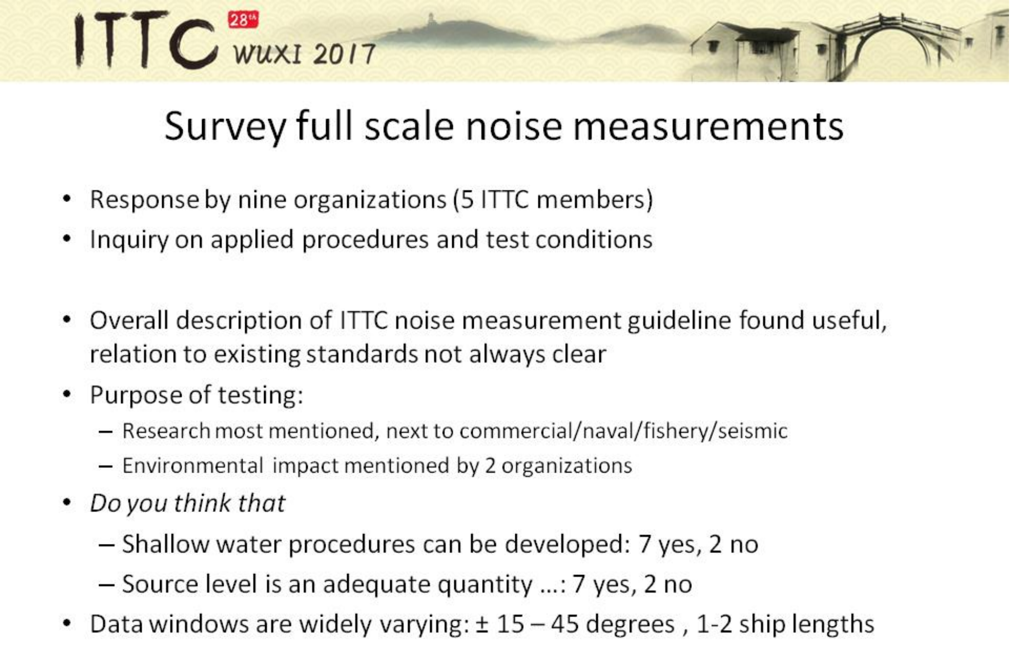
Term of Reference #5:

Check the existing methodologies regarding full scale noise measurements in shallow and restricted water and provide, if possible, guidelines. Establish communication with ISO working groups active on this topic.

- (8) Benchmarking tests

Communication with ISO

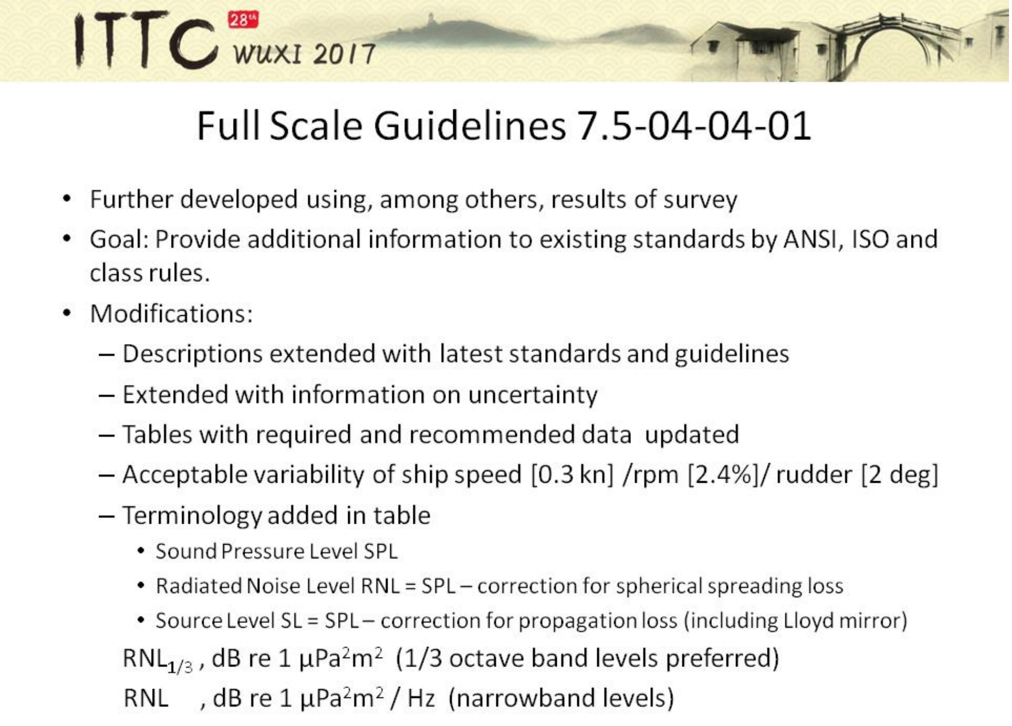
- ITTC is not a legal entity and can not be an official member of ISO
- Only informal exchange of information
  - ISO 17208 (Full Scale Noise Measurements):
    - Through colleagues of working group members
    - ISO draft documents discussed in working group meetings
  - ISO 20233 (Model Scale Noise Measurements):
    - One member active in both working groups
    - ISO draft document discussed in working group meeting
      - No conflicts between ISO standard and ITTC guidelines
      - No joint development pursued



Survey full scale noise measurements

- Response by nine organizations (5 ITTC members)
- Inquiry on applied procedures and test conditions

- Overall description of ITTC noise measurement guideline found useful, relation to existing standards not always clear
- Purpose of testing:
  - Research most mentioned, next to commercial/naval/fishery/seismic
  - Environmental impact mentioned by 2 organizations
- *Do you think that*
  - Shallow water procedures can be developed: 7 yes, 2 no
  - Source level is an adequate quantity ...: 7 yes, 2 no
- Data windows are widely varying: ± 15 – 45 degrees , 1-2 ship lengths

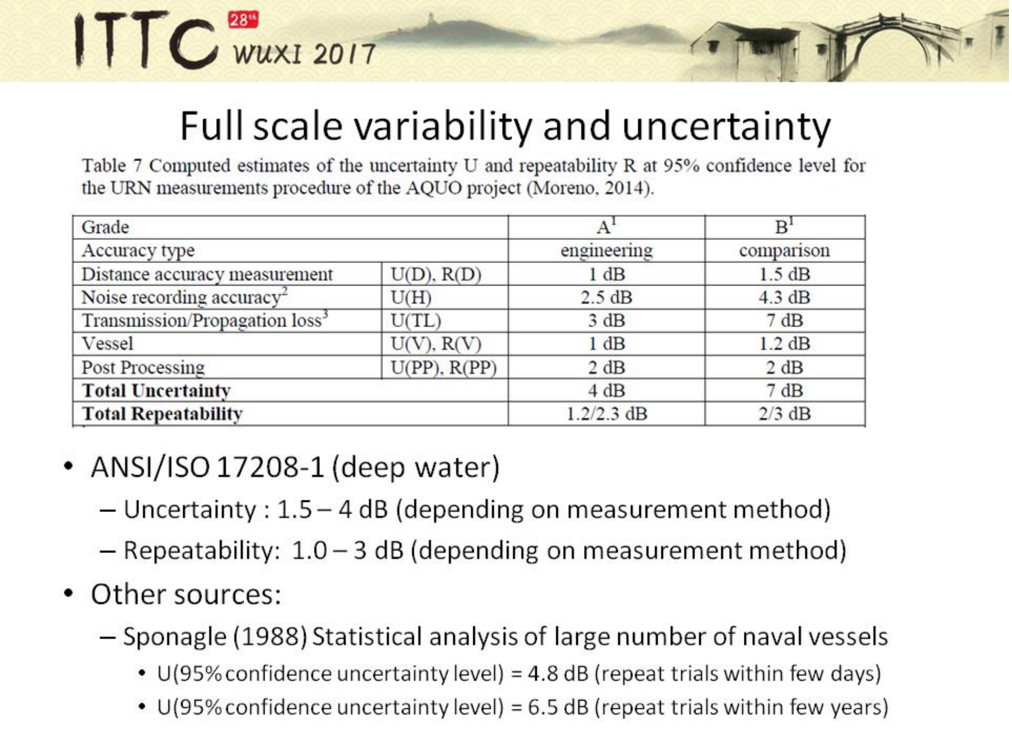


Full Scale Guidelines 7.5-04-04-01

- Further developed using, among others, results of survey
- Goal: Provide additional information to existing standards by ANSI, ISO and class rules.
- Modifications:
  - Descriptions extended with latest standards and guidelines
  - Extended with information on uncertainty
  - Tables with required and recommended data updated
  - Acceptable variability of ship speed [0.3 kn] /rpm [2.4%]/ rudder [2 deg]
  - Terminology added in table
    - Sound Pressure Level SPL
    - Radiated Noise Level RNL = SPL – correction for spherical spreading loss
    - Source Level SL = SPL – correction for propagation loss (including Lloyd mirror)

  $RNL_{1/3}$, dB re 1 μPa^{2}m^2 (1/3 octave band levels preferred)

  RNL , dB re 1 μPa^{2}m^2 / Hz (narrowband levels)

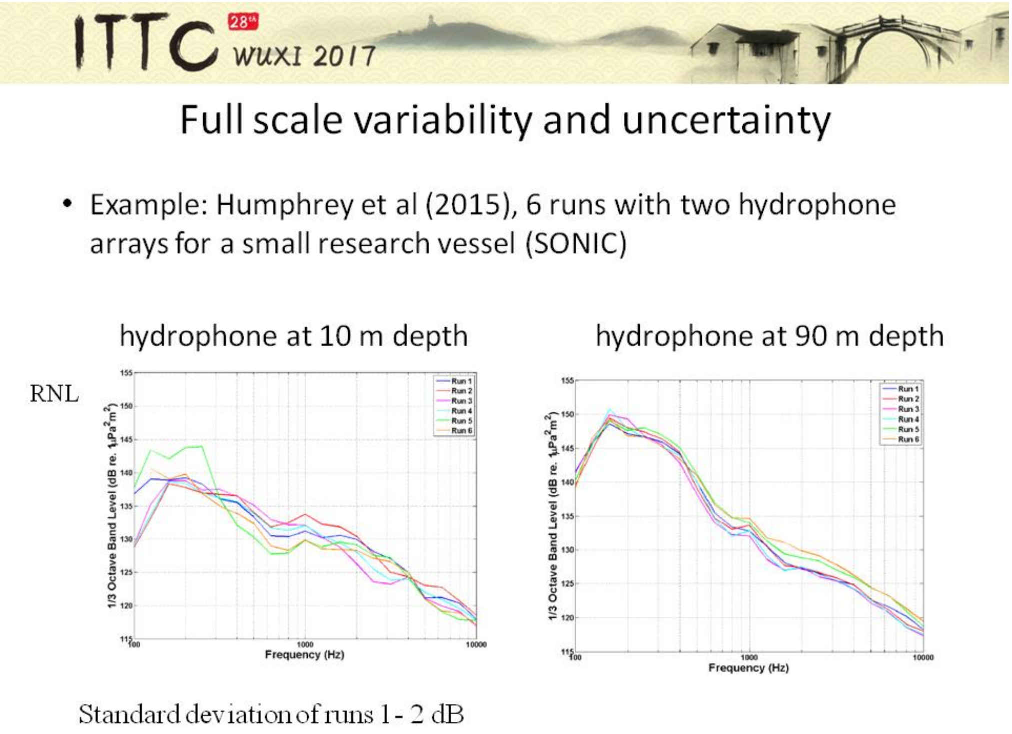


Full scale variability and uncertainty

Table 7 Computed estimates of the uncertainty U and repeatability R at 95% confidence level for the URN measurements procedure of the AQUO project (Moreno, 2014).

Grade		A[1]	B[1]
Accuracy type		engineering	comparison
Distance accuracy measurement	U(D), R(D)	1 dB	1.5 dB
Noise recording accuracy[2]	U(H)	2.5 dB	4.3 dB
Transmission/Propagation loss[3]	U(TL)	3 dB	7 dB
Vessel	U(V), R(V)	1 dB	1.2 dB
Post Processing	U(PP), R(PP)	2 dB	2 dB
Total Uncertainty		4 dB	7 dB
Total Repeatability		1.2/2.3 dB	2/3 dB

- ANSI/ISO 17208-1 (deep water)
  - Uncertainty : 1.5 – 4 dB (depending on measurement method)
  - Repeatability: 1.0 – 3 dB (depending on measurement method)
- Other sources:
  - Sponagle (1988) Statistical analysis of large number of naval vessels
    - U(95% confidence uncertainty level) = 4.8 dB (repeat trials within few days)
    - U(95% confidence uncertainty level) = 6.5 dB (repeat trials within few years)



Full scale variability and uncertainty

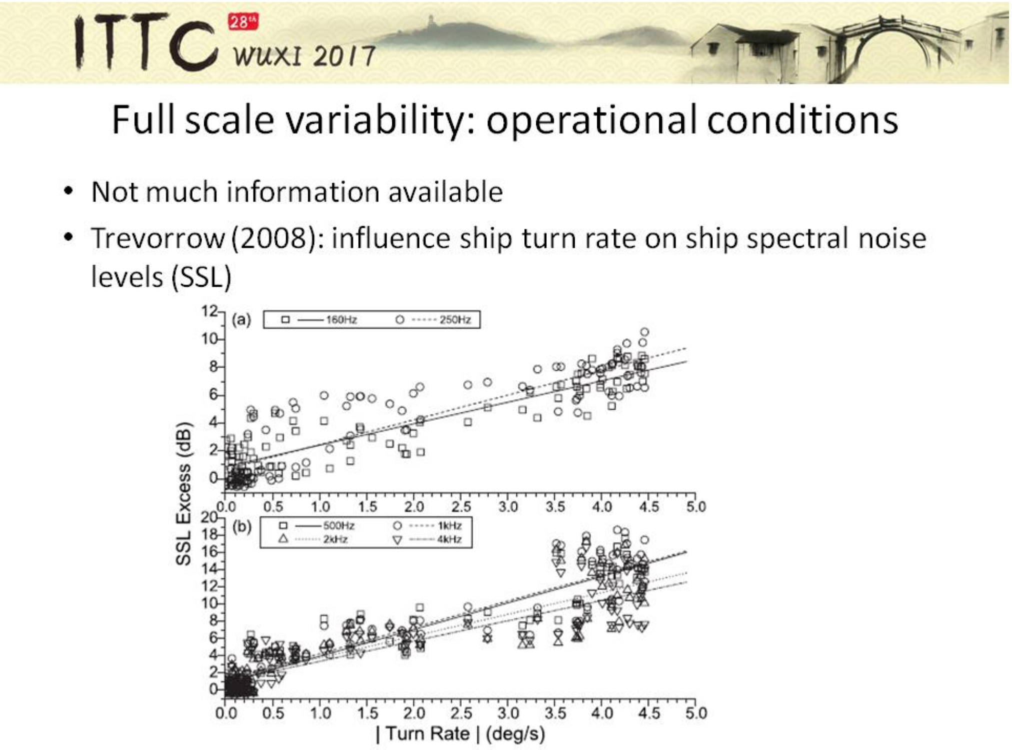
- Example: Humphrey et al (2015), 6 runs with two hydrophone arrays for a small research vessel (SONIC)

hydrophone at 10 m depth

hydrophone at 90 m depth

RNL

Standard deviation of runs 1 - 2 dB

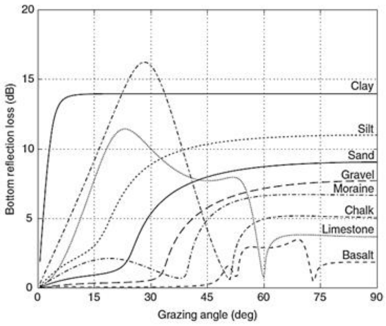


Full scale variability: operational conditions

- Not much information available
- Trevorrow (2008): influence ship turn rate on ship spectral noise levels (SSL)

Full Scale: Shallow water

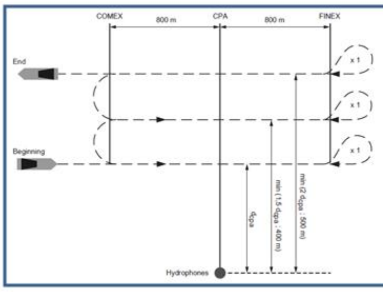
- Reflections between sea bottom and free surface -> wave guide
  - Cylindrical spreading loss, 10 log R, instead of spherical spreading loss, 20 log R
- Urick (1983): Sound velocity profile depends on surface heating and cooling, salinity changes and water currents



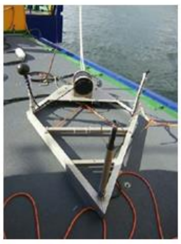
- McKenzie (1962), transmission depends on Seasonal effects influencing temperature gradient / Storms / Tidal changes / Surface waves
- Definition for shallow water depends on organization and precision
- Definitions including ship length might be relaxed when cavitation noise is dominating (not addressed in existing standards !)

Full Scale: Shallow water

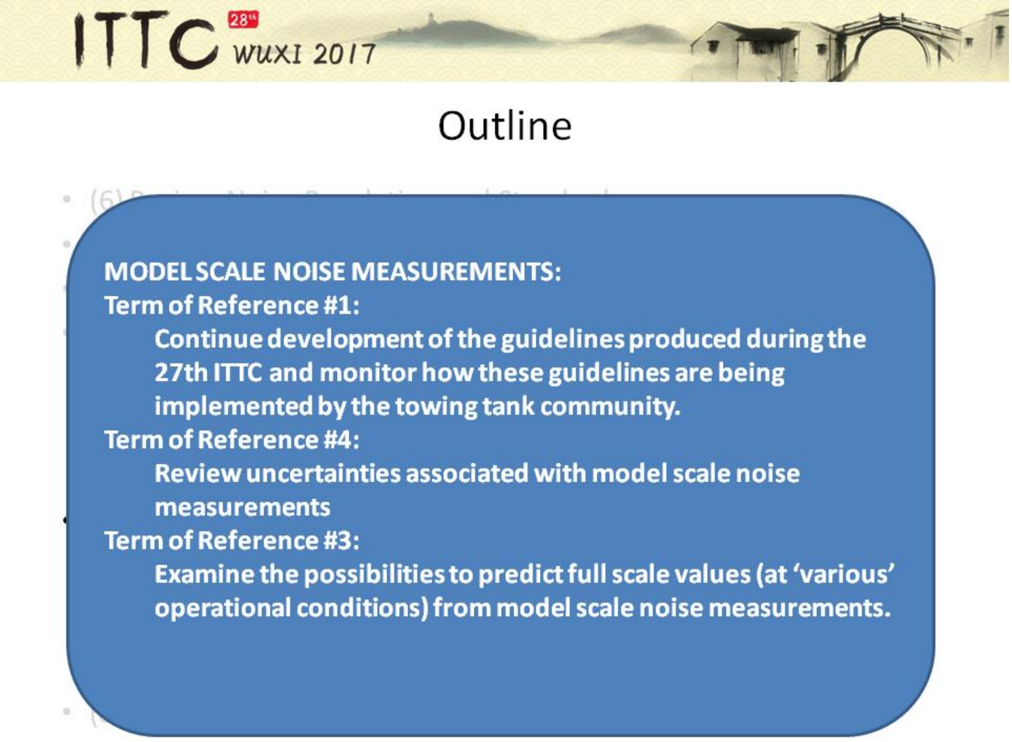
- BV rule, (vary distance between vessel and hydrophone)
  - Transmission loss calculation
    - Scooter / Fields model for f < 1 kHz
    - Bounce / Bellhop model for f > 1 kHz
  - Simple propagation laws (increase uncertainty by 0.5 dB)
    - TL = 19 log(r) :Water depth < 100 m
    - TL= 20 log(r) : water depth > 100 m



- Use of calibrated source



Schael (2014)



Outline

MODEL SCALE NOISE MEASUREMENTS:

Term of Reference #1:

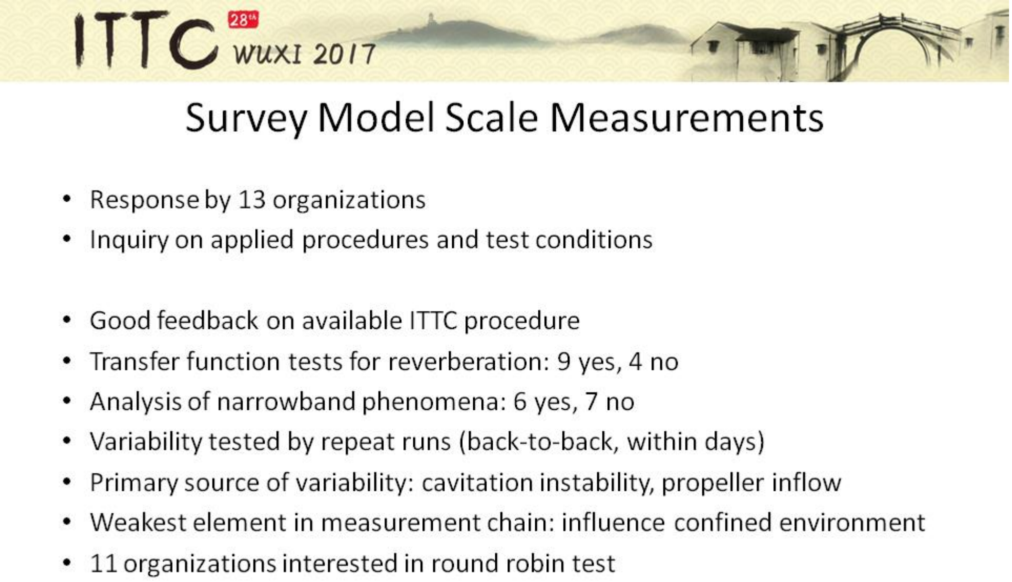
Continue development of the guidelines produced during the 27th ITTC and monitor how these guidelines are being implemented by the towing tank community.

Term of Reference #4:

Review uncertainties associated with model scale noise measurements

Term of Reference #3:

Examine the possibilities to predict full scale values (at 'various' operational conditions) from model scale noise measurements.



Survey Model Scale Measurements

- Response by 13 organizations
- Inquiry on applied procedures and test conditions

- Good feedback on available ITTC procedure
- Transfer function tests for reverberation: 9 yes, 4 no
- Analysis of narrowband phenomena: 6 yes, 7 no
- Variability tested by repeat runs (back-to-back, within days)
- Primary source of variability: cavitation instability, propeller inflow
- Weakest element in measurement chain: influence confined environment
- 11 organizations interested in round robin test

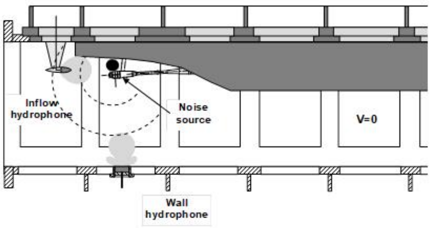
Model Scale Guidelines: 7.5-02-01-05

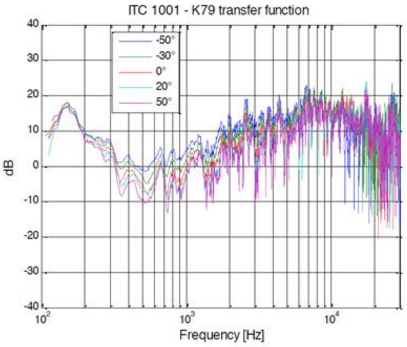
- Updates:
  - General review of text
  - Numbers for cavitation noise scaling shown
    - Low frequency / high frequency
    - Constant bandwidth / proportional bandwidth
    - Remarks on scaling tonals added (low frequency formulation, prop. bandwidth)
  - Application of transfer function discussed in more detail (but lack of literature)
  - Cavitating tip vortex scaling discussed in more detail (but lack of literature)
  - Nomenclature for presenting results modified
    - Sound Pressure Level SPL
    - Radiated Noise Level RNL = SPL – correction for spherical spreading loss
    - Source Level SL = SPL – correction by facility transfer function

  $RNL_{1/3}$, dB re 1 μPa^2m^2 or dB re 1 μPa^2m^2 / Hz

Model Scale Guidelines

- Transfer function measurement





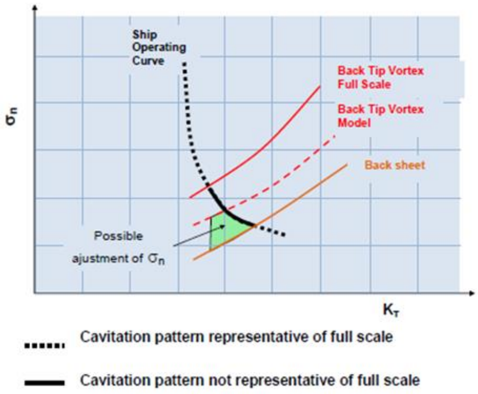
Tani et al. (2015)

- Complexities
  - Type of source
  - Location source
  - Type of signal emitted by source (sweep / white noise / …)

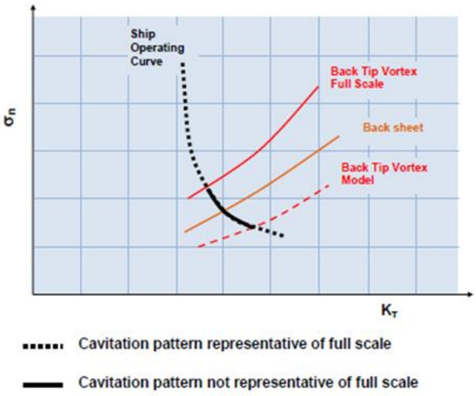
Model Scale Guidelines

- Influence Reynolds number tip vortex cavitation inception

Measurement possible



Measurement not possible



Model Scale: Uncertainties

- No information available from literature !
- Transfer function may depend on sound source (Tani et al. 2015)
- Results questionnaire 28th ITTC

  estimated values by participants !
  - Measured noise levels: 3 - 5 dB
  - Scaling procedure : 3 - 5 dB
  - Total (?) : 4 – 6 dB

- Max differences in round robin tests in 1980's: 10 dB – 20 dB
- Differences in recent common test-cases: 1 dB – 10 dB
  - Depending on case, frequency, …

Model Scale: Prediction of full scale values

Model Scale Aspects

- Ship wake field
- Mean propeller loading
- Cavitation extents and dynamics
- Noise measurements
- Correction of background noise
- Correction for transfer function
- Scaling (two methods available)

- Uncertainty: 4 - 6 dB

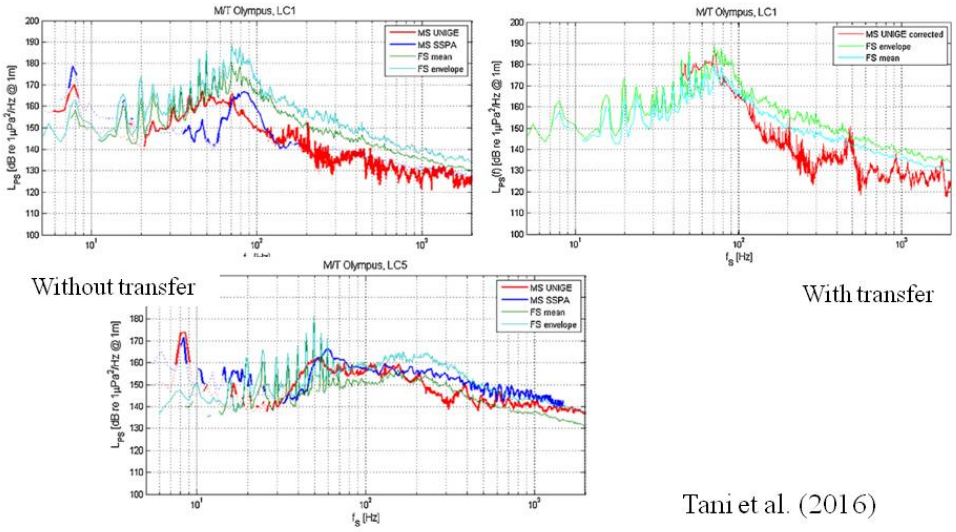
Full Scale Aspects

- Conditions Ship and Propeller
- Ship Draft and Trim
- Sea state and current, rudder angle
- Ship operational conditions
- Cavitation observations
- Noise measurement procedure
- Correction for propagation loss
- Distinction cavitation noise from machinery noise

- Uncertainty: 4 – 7 dB

Model Scale: Prediction of full scale values

- 119 m Oil/Chemical tanker (AQUO) -> Benchmarking candidate



Without transfer

With transfer

Tani et al. (2016)

Outline

Term of Reference #8:

Define and, if possible, conduct benchmarking tests of model test noise measurements, preferably for a ship for which full scale noise measurements are available.

  - (3) Prediction of full scale values
- (8) Benchmarking tests

Benchmarking

- M/T Olympus (AQUO)

2 conditions (CPP)
(4 runs)

Full scale data by SSPA, 3Hydr.
H= 40 m, PL measured
MS tested at
- SSPA
- University of Genova

- Princess Royal (SONIC/HTF)

5 conditions, FPP
Many runs
Full Scale data by U. Southampton and CETENA, 6 Hydr, H= 100 m.
MS tested at
- HSVA
- MARIN
- Rolls-Royce
- University of Newcastle

Benchmarking

- Review of cases

Test Options	Reference	Propeller Type	Model Scale Noise Data	Full Scale Noise Data	Score (0-5)
1a	SONIC EU Project *The Princess Royal* 19 m Catamaran Research Vessel of UNEW	FPP	A	URN, HPF	3.67
1b	*The Princess Royal* propeller with inclined shaft	FPP	A	-	3.75
2a	Seiun-Maru 105 m Single Screw Training Ship, Japan.	FPP	A	HPF	2.00
3	AQUO EU Project 116 m Oil/Chemical Tanker with Single Screw Propeller*	CPP	A	URN	4.33

release hull geometry still pending

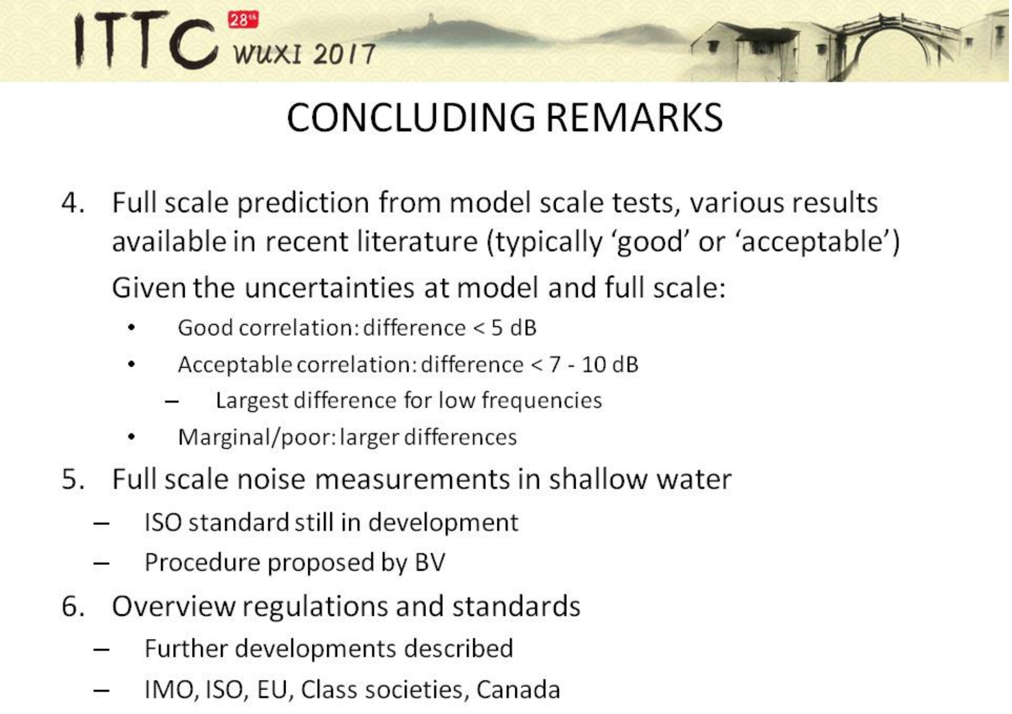
Open water test with inclined shaft used in URN Hydro Testing Forum

No URN available

Propeller geometry available upon request
Release hull geometry pending

CONCLUDING REMARKS

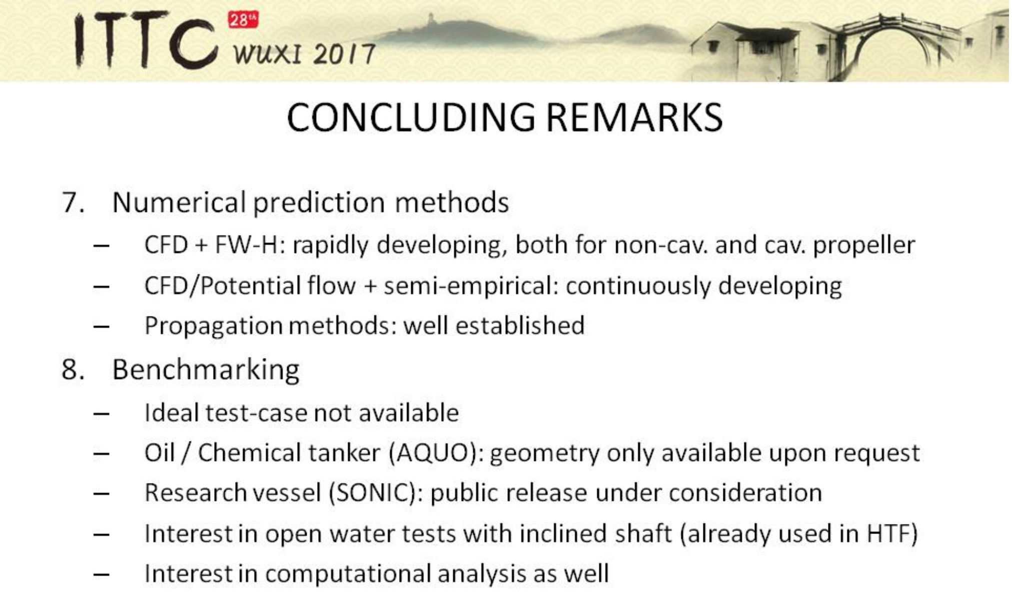
1. ITTC Guidelines
   - Well received by community
   - Model scale guidelines updated
   - Full scale guidelines updated and more descriptive in nature
2. Scale effects
   - Short review given of various items
   - Most attention given to cavitation noise
3. Uncertainties and variability
   - Full Scale: 4 – 7 dB
   - Full scale prediction from Model Scale: 4 – 6 dB (estimated)



CONCLUDING REMARKS

4. Full scale prediction from model scale tests, various results available in recent literature (typically 'good' or 'acceptable')

   Given the uncertainties at model and full scale:
   - Good correlation: difference < 5 dB
   - Acceptable correlation: difference < 7 - 10 dB
     – Largest difference for low frequencies
   - Marginal/poor: larger differences
5. Full scale noise measurements in shallow water
   – ISO standard still in development
   – Procedure proposed by BV
6. Overview regulations and standards
   – Further developments described
   – IMO, ISO, EU, Class societies, Canada



CONCLUDING REMARKS

7. Numerical prediction methods
   – CFD + FW-H: rapidly developing, both for non-cav. and cav. propeller
   – CFD/Potential flow + semi-empirical: continuously developing
   – Propagation methods: well established
8. Benchmarking
   – Ideal test-case not available
   – Oil / Chemical tanker (AQUO): geometry only available upon request
   – Research vessel (SONIC): public release under consideration
   – Interest in open water tests with inclined shaft (already used in HTF)
   – Interest in computational analysis as well

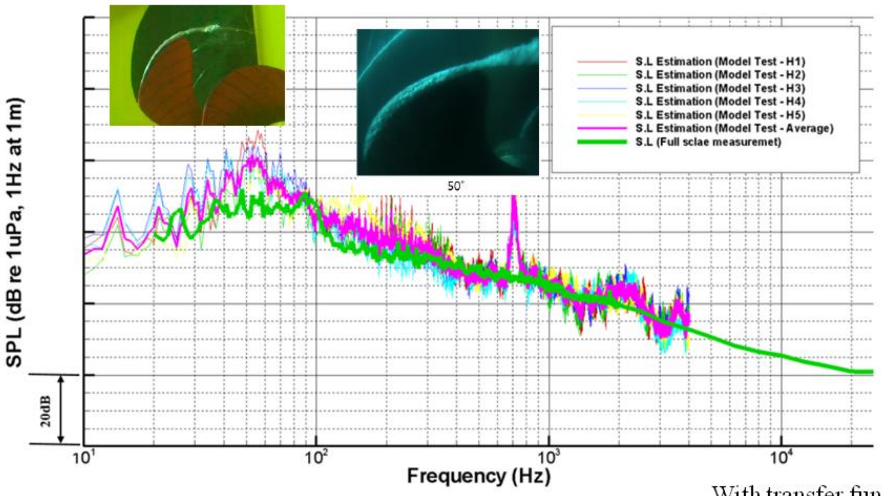
Recommendations

- Adopt guidelines
    - 7.5-02-01-05: Model scale noise measurements
    - 7.5-04-04-01: Full scale noise measurements
- Monitoring progress on shipping noise by IMO, EU, ISO, class societies and other regulatory agencies
- Monitor progress on model scale noise measurements (transfer function, tip vortex scaling)
- Evaluate uncertainties associated with model scale noise measurements of cavitating propeller
- Monitor progress on computational prediction, especially CFD + FW-H
- Continue with definition and conducting benchmarking, including computational analysis

Back-up

Model Scale: Prediction of full scale values

174 m. Product Carrier (design draft MCR)

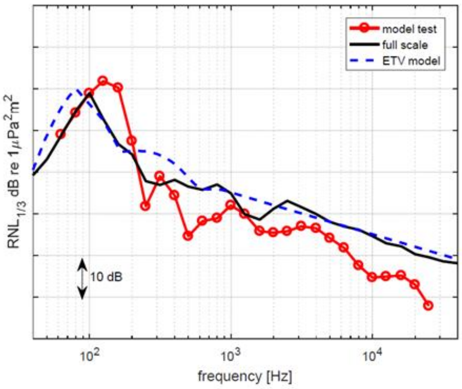


Seol et al. (2015) With transfer function

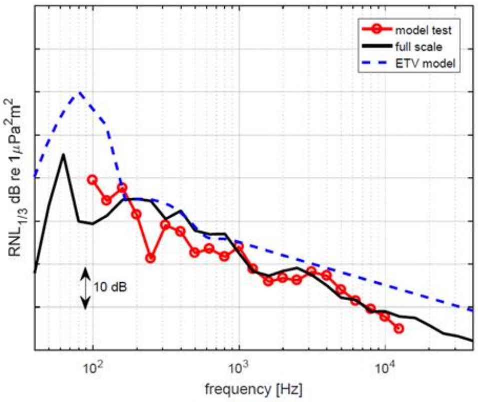
Model Scale: Prediction of full scale values

82 m. combi-freighter (cpp)

High pitch



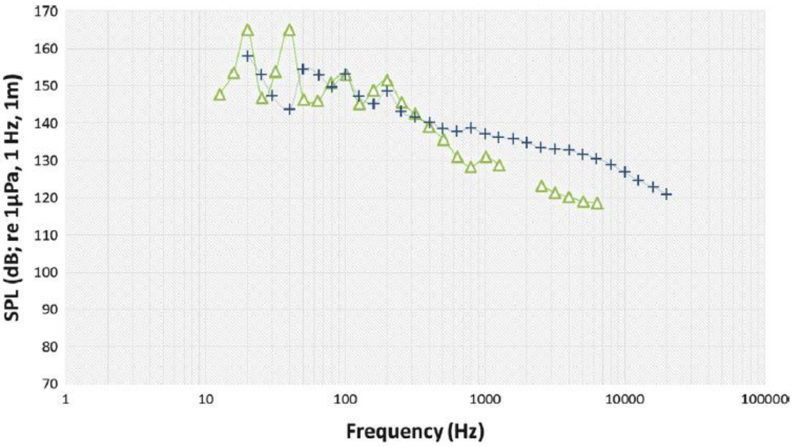
medium pitch



Lafeber et al. (2017) With transfer function

Model Scale: Prediction of full scale values

19 m research vessel (SONIC) -> Benchmarking candidate



Aktas et al. (2016)

Without transfer function

Discusser: Yezhen Pang
Affiliation: China Ship Scientific Research Center
Comments/Question(s):

First, many thanks for the excellent work of the Specialist Committee on Hydrodynamic Noise.

There are two comments about the committee final report:

(1) Regarding the source of noise

In Figure 2 are shown the potential sources of ship generated underwater noise.

As known, the stern hull is vulnerable to the fluctuation of pressure mainly resulted from cavitation of propeller and thereof vibrates and emits noise strongly. Is it better to show such a source of noise individually in Fig.2?

(2) Regarding the Lloyd-mirror effect

The equation (7) is applicable to single hydrophone case as included in ISO 17208-1.

Recently, the draft of ISO 17208-2 has proposed a second-order correction equation as follows for hydrophone geometry of three-hydrophone case to consider the propagation of the Lloyd-mirror effect,

$$\Delta PL = -10log_{10}\frac{14(kd_s)^2 + 2(kd_s)^4}{14 + 2(kd_s)^2 + (kd_s)^4}$$

Response by Committee:

The committee thanks Dr. Pang for his useful comments to the report on Hydrodynamic noise.

Comment 1) The impact of propeller cavitation as a source of stern hull plating vibration has been extensively studied and reported on in numerous ITTC publications. While the principal interest has been related to resulting plating fatigue/failure and inboard noise and vibration, noise radiated by hull vibrations excited by propeller cavitation can also be a source of underwater noise and could have been mentioned in the figure. However, unless special testing procedures are implemented to uniquely identify such noise mechanisms, such noise is indistinguishably blended in with cavitation noise and its levels are an order of magnitude smaller. That is unless the issue is fundamental hull modes that may provide strong amplification of cavitating noise at specific frequencies. As there is very little information available, this topic has not been addressed in the report and we consider it as part of the propeller cavitation noise. The topic of hull scattering is discussed in section 6.2 of the report.

Comment 2) As far as known to the committee, standard ISO 17208-2 has not yet been officially released and the Committee is very reluctant to use information from draft reports of other organizations in the ITTC report. As part of our review of activities by other organisations we have only referred to the character of the activities performed by ISO working groups. However, the equation will appear in the discussions section of the report where it is a welcome addition. To clarify your equation a bit more, we like to add the comment that in your equation k corresponds to the acoustic wave number (k=2πf/c) and ds to the depth of the acoustic source and that the coefficients have been tuned for the hydrophone depths as specified in ISO 17208-1 assuming a flat free surface. For other hydrophone depths the equation might not be valid and the coefficients may need to be adjusted.

Discusser: Jerzy Matusiak
Affiliation: Aalto University
Comments/Question(s):

I congratulate the committee for the excellent report. I have a question and a comment related to the earlier question.

My question relates to the presented figure with power spectral densities of pressures measured at 10m and 90m water depths. What was the water depth in this case? What model of noise propagation (cylindrical or spherical) was used?

Regarding to the earlier question, my experience is that measuring shell plating vibration at ship stern and looking into the measured pressure, the one can define a transfer function which allows to look into the effect of ship vibration on measured pressures.

Response by Committee:

The committee thanks Dr. Matusiak for his discussion to the report.

Question 1:

The mentioned figure corresponds to the figures on sheet 25 of the presentation. The figures were taken from the paper by Humphrey, V., Booker, A., Dambra, R. and Firenze, E. (2015). “*Variability of underwater radiated ship noise measured using two hydrophone arrays*”. Oceans 2015 Conference, Genova, Italy. The water depth was approximately 100 m and the range correction was made using spherical spreading loss.

Response on second remark:

The committee appreciates the opportunity to comment on a topic not addressed in the report which is also related to another question that has been submitted. The committee considered the potential significance of hull vibration as a source of underwater noise. Based on a literature review, it was not clear that this source of noise was considered significant, particularly for commercial vessels at speeds that the propellers are cavitating, which was the primary focus of the committee’s attention. The committee agrees with Dr. Matusiak that based on a vibration-to-noise transfer function, plating vibration levels can be used to estimate this source of underwater noise. The challenge to this effort is in developing the transfer function which would entail use of mechanical shakers at static tests during which the underwater noise is measured or computational tools. These transfer functions have been determined for the underwater noise related to machinery induced hull plate vibration but relevant information on cavitation induced vibration could not be found. This is a topic that should be addressed once publications are available demonstrating its importance.

Discusser: Gerhard Strasser
Affiliation:AC Chairman
Comments/Question(s):

Do you agree that ITTC make an informative submission to IMO (MEPC)?

Response by Committee:

The committee thanks Dr. Strasser for his discussion to the report.

The ITTC can indeed make an informative submission to the IMO-MEPC and present the knowledge and capabilities of the community. However, before submission we recommend to improve upon the model-scale guidelines by extending the section on the determination of the transfer function and to convert the guideline into a procedure. The Committee likes to stress that the ITTC full scale noise measurement guidelines are not a standard for performing full scale noise measurements but rather a description of aspects involved.

Discusser: Michele Viviani
Affiliation: University of Genoa
Comments/Question(s):

Thank you for the comprehensive and very interesting presentation.

I have a question regarding scaling issues. You have shown that there are conditions which we cannot reproduce in model scale. Nevertheless, it is still very important to have the capability to perform some prediction in full scale, especially for some ships in which tip vortex is the only cavitating phenomenon.

Do you think that the use of multiple measurements in off design conditions could be used to this scope, generating generalized spectra, with which we may obtain a prediction?

Response by Committee:

The committee thanks Dr. Viviani for his discussion to the report.

At present there is no established procedure to account for the delay of model scale cavitation inception of tip vortex cavitation in noise measurements of propellers. Adjusting the cavitation number in the test-facility while keeping the thrust coefficient identical to the ship operating point seems a logical choice. The use of multiple measurements, involving changes in cavitation number and possibly changes in thrust coefficient, to obtain trends seems worth while pursuing.

Discusser: Mario Felli
Affiliation:CNR INSEAN
Comments/Question(s):

My comment is related to noise source identification and underlying mechanisms of noise generation which, in my opinion, deserve some attention by the committee.

It is frequent, in my experience at least, that a shipyard (or a navy) comes with a problem related to noise source identification and to the associated noise generation mechanisms (e.g hydrodynamic noise problems associated with installation effects, cavitation, manoeuvring operations) and ask for a solution to fix it. In most of these cases, answers are claimed in a relatively short time.

There is no doubt that CFD is not yet ready to address these problems, particularly when complex hydrodynamics is concerned (cavitation, unsteady operations, installation effects). On the contrary, the adoption of unconventional experimental techniques such as e.g. those devised in the aeronautical experimental field for the study of jet noise & rotor noise (e.g. conditional techniques, scanning techniques, near-far field cross correlation techniques) has been proved to be the only effective way to address the problem both in model scale (see e.g. Felli et al.(2014)[1] on Experiments in Fluids and Felli et al.(2015)[2] on Ocean Engineering) and in full scale (I recently read some interesting papers from a Korean group). I mean these approaches deserve to be mentioned in the Committee Report, the identification of the underlying mechanisms of noise generation and propagation being a relevant, topical issue with many practical implications.

[1] Felli, Grizzi, Falchi "Novel approach for the isolation of the sound and pseudo-sound contributions from near field pressure fluctuation measurements: Analysis of the hydroacoustic and hydrodynamic perturbation in a propeller-rudder system" Experiment in Fluids 55(1) page 1651, 2014.

[2] Felli, Falchi, Dubbioso "Experimental approaches for the diagnostics of hydroacoustic problems in naval propulsion" Ocean Engineering 106, 1-13,2015.

Response by Committee:

The committee thanks Dr. Felli for his discussion to the report.

A review of novel experimental methods for acoustic source localization is indeed not given in the report. The topic was not explicitly mentioned in the Terms of Reference and the workload for the Committee was too high to consider additional activities. However, the topic is very relevant for underwater noise measurements and we provide a concise review of some recent literature below. We suggest that the 29th Specialist Committee on Hydrodynamic Noise considers this relevant topic in more detail.

Localizing sound sources in a cavitation tunnel that contains a reverberant test-section can be performed by processing data from an array of hydrophones. Park et al. (2009) use match field processing in which the measured noise from a cavitating propeller is weighted by a transfer function and an objective function is defined by summing over all frequencies and array transducers. The transfer function is measured by positioning a calibrated sound source at a large number of locations in the propeller disc and measuring the resulting noise by the array. The cavity could be identified but some other noise sources were present as well. Chang and Dowling (2009) successfully apply straight ray propagation and a Monte-Carlo technique to localize collapsing cavitation bubbles in a highly reverberant (small) cavitation tunnel. Lee et al. (2012) show validation tests for a time difference of arrival method using calibrated noise source. The final goal is to localize singing on rotating propeller blades in model experiments. Park (2016) apply beamforming to results obtained with an acoustic array of 45 hydrophones in a large cavitation tunnel to localize the acoustic center of propeller related noise. The acoustic centre of a cavitating propeller operating in the wake of a tanker for conditions with either dominant sheet cavitation or tip vortex cavitation was in good agreement with visual observations of maximum cavitation extents.

The use of hull-mounted sensors to localize the cavitation has also successfully been performed. Van Wijngaarden and Brouwer (2006) and van Wijngaarden (2011) analyze blade rate frequency components using an acoustic boundary element method and search for the location and strength of a single monopole by which the measured data by pressure sensors is reproduced. Kim et al. (2015) use a broadband matched field inversion method to localize incipient tip vortex cavitation noise in the propeller disc. Use is made of a few hydrophones located in the hull directly above the propeller. Foeth and Bosschers (2016) use beamforming techniques to localize cavitation noise sources and estimate the source strength. Use is made of arrays of pressure sensors located above the propeller. Data is presented for model tests in the depressurized wave basin and for sea trials.

Felli et al. (2014) use wavelet filtering to separate hydrodynamic pressure variations from hydroacoustic pressure variations on a rudder behind a non-cavitating propeller. The rudder was equipped with a large array of pressure sensors. The hydrodynamic perturbations were caused by the propeller tip and hub vortices and the acoustic perturbations were correlated with the load variations of the rudder and the shear layer fluctuations of the propeller wake.

In Felli et al. (2015), two experimental approaches are presented for the analysis of hydroacoustic problems concerning with an isolated propeller, a propeller operating in the wake of a surface ship, and an open-water propeller-rudder system. The first approach provides a direct estimate of the flow phenomena at the origin of sound generation and emission through the direct pressure fluctuation measurements combined with detailed flow measurements in the proximity of the noise source; the

latter approach, quite unconventional and for the first time applied in the field of ship hydrodynamics, is based on the application of Tomographic PIV in combination with acoustic analogies. Both methodologies prove to be effective in terms of understanding the noise generation mechanism.

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Chang, N.A. and Dowling, D.R., 2009, "Ray-based acoustic localization of cavitation in a highly reverberant environment". J. Acoustical Society of America, vol. 125 No. 5.

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Felli, M., Falchi, M., Dubbioso, G., 2015, "Experimental approaches for the diagnostics of hydroacoustic problems in naval propulsion", Ocean Engineering 106, Pages 1-19.

Foeth, E.J. and Bosschers, J., 2016, "Localization and source-strength estimation of propeller cavitation noise Using hull-mounted pressure transducers", 31st Symposium on Naval Hydrodynamics, Monterey, California, USA.

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